DESIGN AND SIMULATION OF A SINGLE CYLINDER HIGH SPEED SPARK IGNITION LINEAR ENGINE WITH SPRING SYSTEM

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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LIST OF SYMBOLS

α	Coefficient of thermal expansion
β	Coefficient of convection
δ	Displacement, deflection of the spring
γ	Gas specific heat ratio (C_p / C_v)
ρ	Density of material
ε	Strain
σ	Stress
τ	Shear Stress
$\tau_{\max}$	The maximum of shear stress
Δ	different
ΔT	Temperature different
Ω	Domain
Ω_e	The element of domain
Γ	The boundary of surface
Γ_1, Γ_2	The boundary of surface on the portions 1 and 2 respectively
a	The parameter of Wiebie
A	Area
b	Cylinder bore,
$Bmep$	Break mean effective pressure
C	Constant
C_b	Patton proportional constant of bearing (3.03 X10^{-4} kPa-min/rev-mm)

List of Symbols: Continued

C_g	Bishop gas load constant (C_g=6.89)
C_{ps}	Patton proportional constant of skirt (294kpa-mm-s/m)
C_{pr}	Patton proportional constant of rings (4.06 X 10^4 kPa-mm^2)
C_s	Patton proportional constant of seals (1.22 X 10^5 kPa-mm^2)
d	Wire diameter
D	The mean of diameter of coil
D_{as}	The accessory or balancing shaft bearing diameter
D_{cb}	The connecting rod bearing diameter
D_{mb}	The main bearing diameter
f	Frequency
f_n	The natural frequency
fmep	The friction of mean effective pressure
F	Force, Loading of spring
F_c	The force of combustion
F^e	The element load vector
F_f	The force of the friction
F_l	The force of the loads
F_s	The force of the spring
g	Acceleration gravity, The internal heat generation per unit volume in a three-dimensional domain
G	The shear modulus
$k_x\, k_y\, k_z$	The conductivities of an orthotropic solid
K	The stress constrain factor

List of Symbols: Continued

K	Bishop friction K constant (0.14 for spark ignition engines and 0.29 for diesel engines)
K^e	The stiffness matrix
L	The free length of spring
Lb	The length of bearing
Lmb	The total main bearing length per number f cylinders
L_{cb}	The rod bearing length
L_{as}	The total length of all accessory shaft bearing per number of cylinders
m	The parameter of Wiebe
m	The number of pistons per rod bearing
m	mass
M^e	The element mass matrix
$mpsf$	The mean piston speed factor
$mpssf$	The mean piston speed square factor
n	The number of active coil
n_b	The number of bearing
n_c	The number of cylinders
n_r	The number of cylinder
N	The engine speeds
P	Pressure
P_a	The atmospheric pressure
P_f	The peak cylinder pressure factor
P_f	The fiction power
P_i	The intake manifold pressure

List of Symbols: Continued

Q	Heat release
Q	The number of inactive coil
Qe	The vector of internal force
r	Compression ratio
s	The piston stroke
S	Spring deflection
S_f	Safety livel
t	The time variable of combustion
t_{comb}	The period of combustion
T	Temperature
T_∞	The ambient temperature ambient
U	A characteristic velocity
$\bar{U}_p$	The average of instantaneous piston speed
V	Volume
V_d	The displacement volume
w	The weight function
W	The rate of heat release
x	The displacement of the piston assembly
X	The mass fraction burnt
X	The design vector
X_{max}	The maximum of mass fraction burnt

LIST OF ABBREVIATIONS

BDC	Bottom Dead Centre
BG	Brush Cutter
CAD	Computer-Aided Design
DOF	Degree-of-freedom
FEM	Finite-Element Method
FEA	Finite-Element Analysis
MOA	Multilevel Optimization Approach
ODRO	Operation Design Requirement Optimization
TDC	Top Dead Centre
SAE	Society of Automotive Engineers
SAE6150	SAE standard of chrome-vanadium alloy steel wire

ABSTRACT

This thesis deals with the design of a single cylinder high-speed spark ignition linear engine with a spring system return cycle. The main objective of the research is to design and analyse a free piston linear engine that is easy to start, easy to maintain and easy to control. The unique design of the spring as a return cycle in a free piston linear engine is presented and its effects on engine performance and motion are discussed. The engine performance has been predicted the aim is to design a linear engine particularly for the spring system. The spring design has been optimised by using a multilevel optimization approach. Based on the optimisation of the spring design, the linear engine geometry design has been conducted. The performance of the linear engine design has been measured and the results compared with the predicted performance. Besides which the motion of the linear engine has been studied; however, friction affect show the rotated of the piston. It is necessary to modify the spring mechanism to ensure that the scavenging process works properly. Two scenarios such as the removal of the bottom part of the piston skirt and adding a lock to the connecting rod are recommended, based of structural stress and thermal-structural stress analysis. Software has been used in the research to analyse the design of the free piston linear engine with a spring system, including GT-Power, SolidWorks, Matlab, Algor, and Spread-Sheet. The model has been built using GT-Power to predict the engine performance. To validate the model, it has been assessed with the original engine manual and experimentally. Three step multilevel optimisation of the spring geometry has been carried out by using Matlab and Spread-Sheet. SolidWorks has been used to design all of the components and for the assembly of the linear engine. Cosmos motion, which is a part of the SolidWorks facility, has been used to analyse the piston dynamics of the linear engine. Once again, GT-Power has been used to analyse the effect of the spring design on the linear engine performance. For the modification of the design of the spring system, Algor has been used to analyse the thermal-structural stress of the piston and the connecting rod. Through step by step considerations started from building model to predict the performance of linear engine, to optimize the spring geometry design then continued build the free piston linear engine with spring system including design, analyses and modified. The result is a design which predicts the performance and the dynamics of piston motion. Only 50% of the 12 speeds sampled worked correctly. The rotation of the piston on the Z-ordinate can be fixed through modification of the piston or connecting rod. A design of a single cylinder high-speed spark ignition linear engine with spring system as return cycle has been carried out. Although the range of speeds was narrow compared to a conventional engine, the maximum power output is still higher. The final design result was 1.03 kW at 3.6 m/sec.
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ABSTRAK

Tesis ini berkaitan dengan merekabentuk sebuah enjin pencucuhan bunga api berkelajuan tinggi yang berbentuk enjin linier dengan menggunakan sistem pegas sebagai kitar kembali. Tujuan utama kajian ini adalah untuk merekabentuk dan mengkaji enjin linier putaran bebas yang mudah dimulakan, mudah dibuat penyenggalaran dan senang dikawal. Keistimewaan pegas sebagai kitaran kembali didalam enjin linier piston bebas telah ditunjukkan dan pengaruhnya keatas prestasi enjin dan pergerakannya dibincangkan. Prestasi enjin telah diramalkan mengikut rekabentuk enjin linier terutama menggunakan mekanisme pegas. Rekabentuk pegas telah dioptimumkan dengan pendekatan pengoptimum secara berperingkat. Berdasarkan keputusan optimasi rekabentuk pegas, geometri daripada rekabentuk enjin linier telah dapat dilakukan. Prestasi rekabentuk enjin linier telah dikaji dan hasilnya dibandingkan dengan prestasi ramalan. Selain itu, daripada pergerakan enjin linier yang telah dipelajari geseran dapat ditunjukkan dengan pengaruh pusingan piston. Dengan itu pergerakan mekanisme pegas perlu ditukar untuk dapat memastikan proses menghapus sisa boleh bekerja dengan baik. Dua keadaan yang mana pemotongan bahagian bawah dinding piston dan penambahan kekunci pada rod penyambung dicadangkan mengikut kajian ketegangan struktur dan ketegangan terma-struktural. Beberapa perisian telah digunakan kerana untuk mengkaji rekabentuk enjin linear piston bebas dengan sistem pegas, iaitu GT-Power, SolidWorks, Matlab, Algor, dan Spread-Sheet. Sebuah model telah dibina dengan menggunakan GT-Power untuk meramal prestasi enjin. Untuk pengesahan model ini telah dibuat pemeriksaan dengan menggunakan buku panduan asli dan eksperimen. Dengan menggunakan Matlab dan Spread-Sheet untuk mendapat optimum peringkat ketiga bagi merekabentuk geometri pegas. SolidWorks telah digunakan untuk merekabentuk semua bahagian dan pemasangan enjin linier. Cosmos Motion yang merupakan sebahagian daripada kemudahan SolidWorks telah digunakan untuk mengkaji dinamik piston daripada enjin linier. GT-Power telah digunakan sekali lagi untuk mengkaji kesan daripada rekabentuk pegas pada prestasi enjin linier. Untuk mengubahsuai rekabentuk sistem pegas, Algor telah digunakan untuk mengkaji tegangan terma-struktur daripada piston dan rod penyambung. Melalui langkah demi langkah bermula daripada pertimbangan pembentukan model untuk meramal prestasi enjin linier, untuk optimasi perancangan geometri pegas seterusnya membina enjin linier piston bebas dengan sistem pegas, iaitu merekabentuk, mengkaji dan mengubahsuai. Hasilnya adalah sebuah rekabentuk yang telah diramal prestasi dan gerak dinamik daripada piston nya. Dari 12 kelajuan sebagai pembolehubahnya hanya 50% kelajuan boleh bekerja dengan baik. Putaran piston pada paksi Z boleh diperbaiki dengan pengubahsuaian dari piston atau rod penyambung. Rekabentuk enjin pencucuhan bunga api berkelajuan tinggi enjin linier dengan menggunakan sistem pegas sebagai kitar kembali telah dilakukan. Walaupun kelajuan enjin menurun berbanding dengan enjin konvensional, tetapi output kuasa maksimum masih lagi tinggi. Keputusan rekabentuk akhir adalah sebanyak 1.03 kW pada 3.6 m/saat.

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